Comparison of Patrick Bayou Benthic Community to Reference Tidal Streams in Galveston Bay, Texas

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Introduction

Patrick Bayou is a small tributary to the Houston Ship Channel (HSC) that was placed on the National Priorities List as a Superfund site in 2002 by the EPA for elevated contaminants in sediment. The process to address that contamination is continuing with the recent completion of a draft Baseline Ecological Risk Assessment (BERA), in August 2012 (Anchor 2012). One of the ecological receptors evaluated in the Patrick Bayou draft BERA was the benthic invertebrate community. The risk question presented in the draft BERA was: “Is the condition of the benthic community below acceptable thresholds due to exposure to sediment COPC?”

Patrick Bayou sediments are significantly contaminated. In the superfund process, sediments were sampled at 46 stations distributed throughout the bayou (Anchor 2010) to determine the current levels of contamination. The site average for several contaminants exceeded effects-range median (ERM) sediment quality guidelines (Long et al. 1995), including mercury (average 23.5 mg/kg compared to an ERM of 0.71 mg/kg), PCBs (average in Patrick Bayou of 13.2 mg/kg compared to an ERM of 0.180 mg/kg), and total PAHs (average 56.2 mg/kg compared to an ERM of 44.792 mg/kg). Additionally, the site average concentrations for each of the seven low molecular weight PAHs (where ERM levels have been established) were higher than the corresponding ERM values, as was the total of the low molecular weight PAHs. Three of the six high molecular weight PAHs exceeded their ERM levels and all six exceeded the ERM levels in some samples. The site average for total high molecular weight PAHs (24.1 mg/kg) exceeded the ERM of 9.6 mg/kg.

Benthic invertebrates are in direct contact with sediment and pore water and are known to respond to pollutant stresses (Brown et al. 2000). Macrobenthic invertebrates are an important component of the estuarine ecosystem and food web and they can also accumulate toxicants from the sediment and transfer those to the rest of the system (Gibson et al. 2000). In the draft BERA, the benthic invertebrate community was assessed and found to not differ significantly from local comparison sites (Anchor 2012), in spite of the significant sediment contamination in Patrick Bayou. The purpose of this paper is to present a more detailed evaluation of the Patrick Bayou macrobenthic community, and to compare it with the benthic communities found in other tidal tributaries within the Galveston Bay system.

Background

Macrobenthos in Patrick Bayou have been sampled several times since 1994. As a part of a special study on sediment contamination, Broach and Crocker (1996) collected macrobenthic samples at 4 sites within and 2 sites near Patrick Bayou in July 1994. During TMDL initiated sampling, a consortium of the industries that discharge to Patrick Bayou collected macrobenthic samples at 18 stations within and 1 station near Patrick Bayou in September 2000 and in April 2001 (Parsons et al. 2002). In October 2001, the Patrick Bayou industries collected samples at 4 stations in Patrick Bayou (Parsons et al. 2002). In August 2003, 6 additional macrobenthic community samples were collected jointly by the Patrick Bayou industry group and the TCEQ regional office personnel. Four of the benthic samples from August 2003 were split between the industry contractors and the TCEQ. Sediment contaminant levels and sediment toxicity were evaluated concurrently with the benthic community in each study.

The draft BERA focused on the Patrick Bayou benthic community samples collected between September 2000 and August 2003 that were within the area designated as the superfund site (Anchor 2012). In the draft BERA, Patrick Bayou ("site") benthic community samples were compared to benthic samples collected in 2004 and 2005 by Dobberstine (2007) in several other Galveston Bay tributaries that were intended to be similar to Patrick Bayou. Dobberstine evaluated the sediment quality and performed toxicity tests on sediment samples collected from those tributaries, specifically to determine if they would be suitable reference sites for Patrick Bayou. This approach is consistent with EPA guidance that suggests using a population of reference sites to evaluate the status of benthic communities (Gibson et al. 2000). However, the sample collection methods used in Dobberstine's study were different from those used in Patrick Bayou. The most important difference was in the amount of sediment collected to make up a given sample, where Dobberstine collected only 393 cm^2 per sample compared to the 929 cm^2 per sample collected in the other studies. Because of this difference, the benthic community data samples should be compared with caution.

This white paper will compare the Patrick Bayou benthic community data and the Dobberstine data to another population of reference sites evaluated by the TCEQ using the same sediment collection methods used for Patrick Bayou.

Methods

For this white paper, the benthic community data were divided by season. Summer and spring samples were considered separately because Galveston Bay macrobenthic communities change seasonally and are generally more abundant and diverse in spring and fall compared with summer (Broach 2001, Harper 1992). The draft BERA presented community data for a few fall (Patrick Bayou) and winter (Dobberstine) sample events as well, but those are not considered here because the TCEQ does not have tributary reference data from those seasons.

Patrick Bayou benthic community sample locations were divided into 2 groups: 1) the main portion of the bayou and 2) the upper portion of the site, which is gunite-lined. The gunite-lined area is not ideal habitat for infaunal macrobenthos because the sediment is less stable than in other estuarine areas, especially during periods of high flow. The main portion of Patrick Bayou has permanent soft-sediment as substrate. This includes the lower 2 km of the bayou, beginning just upstream of the confluence with the east fork of the bayou and continuing to the mouth of the bayou at the confluence with the Houston Ship Channel. Eleven of the Patrick Bayou sample sites were in the main portion of the bayou and the other 4 sites were in the gunite-lined reach of the bayou. The benthic data evaluated in this paper are provided in Appendices for clarity. The summer samples from Patrick Bayou are summarized in Appendices 1-3, while the spring samples from Patrick Bayou are in Appendix 4 (main) and Appendix 5 (gunite).

The benthic data collected by Dobberstine from Cedar Bayou, Double Bayou, and Robinson Bayou were provided in the draft BERA and are reproduced in Appendix 6 (summer) and Appendix 7 (spring). The Dobberstine sediment samples were collected using a 10 cm diameter coring device (sample area = 79 cm^2). Five replicates were combined to make up one sample. Two or three stations were located on each bayou, and sample locations were selected to minimize the effects of anthropogenic sources.

The TCEQ benthic community samples used for comparison were collected from several Galveston Bay tidal tributaries. Samples were collected during a 1997 study of the effects of point sources on Galveston Bay sediments (Guillen et al. 1999) and during a 2001 study of Armand Bayou (TCEQ unpublished data). The TCEQ reference samples used fit *a priori* criteria similar to those used by Engle and Summers (1999) to identify reference sites. This included sample locations where no sediment contaminant concentrations exceeded the effects range-median (ERM) from Long et al. (1995), no more than 3 contaminants exceeded the effects range-low (ERL, Long et al. 1995), the surface water dissolved oxygen concentration was > 4 mg/L at the time of sampling, and that also showed no significant toxicity to any laboratory test organisms used. To ensure that the comparison sample locations would be as similar as possible to the expected benthos in Patrick Bayou, only samples collected from tidal streams were used (not open bay samples or side bay samples) where surface water salinity was less than 18 parts per thousand (ppt) at the time of sampling. Of the 50 sample locations from the 1997 study, only 6 locations met these criteria. Three summer sample locations from the Armand Bayou study also fit the criteria and were included in the tributary comparison group. The tidal tributaries represented in this summer data set included the San Jacinto River, Dickinson Bayou, Clear Lake, and Chocolate Bayou (Table 1). The Armand Bayou study also included spring samples for macrobenthos, and seven of those samples fit the criteria to be included in this analysis. The spring sample locations in Armand Bayou are the same as those used for summer data, along with another station upstream. The other spring sample locations came from an upper and middle station in Halls Bayou, which is a tributary to Chocolate Bayou. Benthic samples were collected at all these sites in spring and summer. However, many of the summer samples did not meet the dissolved oxygen criteria. Data from these sample events are shown in Appendix 8 (summer) and Appendix 9 (spring).

Table 1. TCEQ samples used in the summer reference group.

StaID		Name	Date	Seg	Latitude	Longitude	Depth	DO	Sal
11198	SS3	SJR northwest of Highlands	7/24/1997	1001	29.8242	-95.0792	2.1	5.25	3.1
16985	SS36	Clear Lake at Nassau WWTP	6/30/1997	1101	29.5333	-95.0908	1.2	6.4	3.5
11457	SS24	Dickinson Bayou near Gum Bayou	7/8/1997	1103	29.4647	-95.0108	2.1	7.93	5.6
16983	SS25	Dickinson Bayou upstream of 146	7/8/1997	1103	29.4606	-94.9751	1.5	7.82	9.9
16973	SS26	Chocolate Bayou near Amoco	7/15/1997	1107	29.2183	-95.2096	0.6	7.54	6.5
16971	SS28	Chocolate Bayou downstream of 2004	7/15/1997	1107	29.2091	-95.1981	0.6	6.2	12.1
11500	ABLS	Armand Bayou Lower Reach	7/29/2002	1113	29.5759	-95.0715	1.5	6.9	6.2
11503	ABMC	Armand Bayou Middle (Center)	7/29/2002	1113	29.5968	-95.0907	2.3	7	0.6
11503	ABMS	Armand Bayou Middle (Side)	7/29/2002	1113	29.5968	-95.0907	0.5	7.3	0.6

To make the benthic data from the different studies more comparable to one another, organisms that are not part of the benthic infaunal community were removed from all data sets. This included planktonic organisms (e.g. copepods), meiofaunal organisms (e.g. nematodes), and larger organisms such as small fish, crabs, and penaeid shrimp.

The sample collection methods used in the Dobberstine study were different from those used in the collection of the Patrick Bayou samples and the TCEQ samples. For the TCEQ and Patrick Bayou samples, a 232 cm^2 Ekman grab was used to collect four replicates, which were combined to yield a sample comprised of 929 cm^2 of sediment. In the Dobberstine study, one sample was the sum of five 79 cm^2 cores for a total of 393 cm^2 of sediment collected.

To estimate the effect of the different sample areas on the community metrics considered here, each of the 9 TCEQ reference samples (929 cm^2) were divided into 2 samples of two replicates each by taking the results from the first 2 replicates as a sample and the results from replicates 3 and 4 as a sample. (The original assignment of numbers to replicates was random.) These smaller TCEQ samples (464 cm^2) are closer in area to the Dobberstine samples (393 cm^2). The biological metrics were computed on the resulting 18 “small” samples and those results were compared to the original 9 “large” samples. Because the same community data are used, any differences in metric values between the 18 small samples and their 9 parent samples should be attributable to their different sample areas.

Biological Metrics

Benthic communities are generally evaluated using metrics that respond to disturbance. Macrobenthic communities respond to disturbance with an increase in tolerant or opportunistic organisms (Grassle and Grassle 1974, Gibson et al. 2000, Lerberg et al. 2000, Dauer et al. 1992, Dauer 1993, Weisberg et al. 1997, Brown et al. 2000), a decrease in total species (Dauer et al. 1992, Dauer 1993, Gibson et al. 2000, Lerberg et al. 2000) or diversity (Gibson et al. 2000, Weisberg et al. 1997), and a loss of sensitive species or groups (Gibson et al. 2000, Dauer et al. 1992, Dauer 1993). The Patrick Bayou benthic community data were compared to that of other tributaries in terms of the number of taxa per sample, Shannon-Weiner diversity ($H' = \sum pi \ln(pi)$), the proportion of intolerant organisms, the proportion of tolerant organisms, the percent of the sample dominated by a few species, and the presence or absence of certain taxonomic groups. These specific metrics were used in this analysis, not just because they are commonly used in estuarine benthic analyses, but also because they were the metrics that were the most effective in differentiating between reference and stressed samples in an analysis of 94 benthic samples from Galveston Bay tributaries (TCEQ unpublished data). This metric validation is an important step in the development of a multimetric index (Gibson et al. 2000).

Percent Tolerant and Intolerant

The designation of a species as “tolerant” or “intolerant” was based on scientific literature where individual species were classified as either pollution-indicative or pollution-sensitive (Brown et al. 2000, Dauer et al. 1992, Lerberg et al. 2000, Ritter and Montagna 1999, Roach et al. 1992, Weisberg et al.1997). Taxa indicative of metal and organic contaminated sites (Rakocinski et al. 1997) were also considered tolerant for this analysis. Specific references for the designation of each species are given in Table 2 for tolerant species and Table 3 for intolerant or pollution-sensitive species.

Table 2. Tolerant/Opportunistic/Pollution Indicative Taxa.

Group	Taxa	Reference
Oligochaeta	Oligochaeta	Brown et al., 2000; Ritter and Montagna, 1999; Weisberg et al., 1997
Polychaeta	*Capitella* spp	Rakocinski et al., 1997; Weisberg et al., 1997
	Laeonereis culveri	Lerberg et al., 2000
	Paraprionospio pinnata	Dauer et al., 1992; Weisberg et al., 1997
	Streblospio benedicti	Dauer et al., 1992; Rakocinski et al., 1997; Ritter and Montagna, 1999; Roach et al., 1992; Weisberg et al., 1997
Insecta	Chironomidae	Weisberg et al., 1997
Mollusca	*Macoma mitchilli*	Rakocinski et al., 1997
	Mulinia lateralis	Dauer et al., 1992; Weisberg et al., 1997

Table 3. Intolerant/Pollution Sensitive Taxa

Group	Taxa	Reference
Polychaeta	*Aricidea philbinae*	Rakocinski et al., 1997
	Asychis elongata	Dauer et al., 1992; Weisberg et al., 1997
	Clymenella torquata	Dauer et al., 1992; Weisberg et al., 1997
	Diopatra cuprea	Dauer et al., 1992; Weisberg et al., 1997
	Glycera americana	Weisberg et al., 1997
	Glycinde solitaria	Weisberg et al., 1997
	Heteromastus filiformis	Lerberg et al., 2000
	Mediomastus	Brown et al., 2000; Weisberg et al., 1997
	Spiochaetopterus costarum	Weisberg et al., 1997
	Spiophanes bombyx	Weisberg et al., 1997
Crustacea	*Listriella clymenellae*	Weisberg et al., 1997
Mollusca	*Cyrtopleura costata*	Dauer et al., 1992; Weisberg et al., 1997
	Rangia cuneata	Dauer et al., 1992; Weisberg et al., 1997
	Tagelus divisus	Dauer et al., 1992; Rakocinski et al., 1997; Weisberg et al., 1997
Nemertea	Nemertea	Lerberg et al., 2000
Echinodermata	*Micropholis atra*	Dauer et al., 1992; Weisberg et al., 1997

Major Taxa

Crustaceans, polychaetes, bivalves, gastropods, and nemerteans are all important components of the benthic community. To quantify this taxonomic diversity, these 5 groups were combined into one metric ("major taxa"). The computation of this metric was based on the presence or absence of each of these groups in the sample. One point was assigned for the presence of each of these major taxa in the sample. If all five were present, the value of the metric was 5. If none were present, the value of the metric is zero.

Tidal Stream Benthic Index

Another way to evaluate benthic communities is to use a benthic index that combines several metrics into a single score. These indexes can be more informative than individual metrics, depending on their application. According to EPA guidance, multimetric indexes are not a one-size-fits-all tool; they instead must be modified for specific regional conditions (Gibson et al. 2000).

For this white paper, the six metrics described earlier were combined into one index using the following formulas (Table 4). This aggregation of metric scores allows all of the information in the individual metrics to be integrated into one score (Gibson et al. 2000). Before they were combined, the six metrics were standardized and were scaled to a range from 0 to 10. For the metrics that were higher in the reference group, the raw values were divided by the 90th percentile for the reference group (the 32 samples in the original TCEQ dataset) and then multiplied by 10, except for major taxa, which was multiplied by 2. However, if the metric was higher in the stressed group in the original analysis, it was scaled to the 10th percentile of the reference group. The 90th (and 10th) percentiles are shown in Table 4. The final benthic index score is the sum of the six metric scores with the possible range of scores from 0 to 60.

The analysis in the draft BERA used two multi-metric indexes developed for Gulf of Mexico estuaries (Engle and Summers 1999, TetraTech 2011) to compare Patrick Bayou benthic data with that collected by Dobberstine. Both of these indexes were developed using benthic data based on samples collected primarily in open-bay habitats, with very few tributary samples included, so they would not be appropriate to use in Patrick Bayou, unless they were shown to differentiate known reference and degraded tidal stream samples. Classification of reference or degraded (or stressed) was based on sediment chemistry (number of contaminants exceeding Long et al. sediment quality guidelines), sediment toxicity, and water column dissolved oxygen levels (Engle and Summers 1999, TetraTech 2011).

Table 4. Metric Score Calculations. Formulas used to combine the six individual metrics into a single index score.

Metric		Tidal Stream Reference Group 90th %ile (or 10th)	Computation of Metric Score	Range**
Taxa	# of taxa in sample	13	(Taxa/13)*10	0 to 10
Diversity	H' = Shannon-Weiner diversity	1.85	(Div/1.85)*10	0 to 10
Major Taxa	Polychaeta, Crustacea, Nemertea, Bivalvia, Gastropoda	5	#MajorTaxa*2	0 to 10
% Intolerant	% of individuals from intolerant taxa (see list)	0.70	(%Intol/0.70)*10	0 to 10
% Tolerant*	% of individuals from tolerant taxa (see list)	0.16 (10th %ile)	10*(1-%Toler)/(1-0.16)	0 to 10
% Dominant*	% of the sample from the top 3 species	0.71 (10th %ile)	10*(1-%Dom)/(1-0.71)	0 to 10

*If no orgs present in sample, value of metric is 0.

**If a metric score exceeds 10, it is set equal to 10.

Diversity, number of taxa, major taxa, and the overall scores were compared between groups using an analysis of variance (ANOVA) with Tukey's post hoc test (Minitab 2000) to determine which means were different. The proportions of tolerant and intolerant organisms and percent dominance were compared using a Kruskal-Wallis test of the medians (Minitab 2000).

Results

Differences between the groups of benthic samples were most pronounced in the summer (compared to the spring). Boxplots of the summer data are shown in Figure 1 for all six of the individual metrics considered. For all of the metrics, the two Patrick Bayou sample groups (the bayou below the gunite and the gunite-lined portion of the bayou) were not significantly different from one another. In most cases, the two groups of reference samples (TCEQ and Dobberstine) were also not significantly different from one another.

<u>Taxa</u>

Both groups of Patrick Bayou summer macrobenthic samples demonstrated significantly fewer taxa ($p<0.001$) than the two reference tributary groups. There was no significant difference between the two Patrick Bayou groups or between the two reference groups in terms of taxa. In the summer, taxa per sample averaged 4.8 for the main part of the bayou and 2.8 in the gunite portion of Patrick Bayou. This contrasted with 10.8 taxa per sample in the TCEQ comparison group and 9.8 in the tributaries sampled by Dobberstine (Table 5). In the analysis of the effect of sample size, the samples based on the smaller area averaged only 8.5 taxa compared with 10.8 taxa in the standard sample. Seasonally, Patrick Bayou contained more taxa in the spring samples than in the summer samples (average 7.5 vs. 4.8), and there were at least 3 taxa in all the Patrick Bayou spring samples. The difference between the Patrick Bayou community data and that for the comparison locations was less pronounced in spring than in summer. The average taxa per sample in Patrick Bayou was about 65% of the average in the TCEQ reference sites for the spring (7.5 vs. 11.4). In contrast, less than half as many taxa were found in Patrick Bayou in the summer samples compared to the reference group locations (4.8 vs. 10.8).

Table 5. Number of taxa per sample by group and by season.

TAXA					
Summer	N	Mean	StDev	Min	Max
TCEQ	9	10.8	3.07	5	15
Dobberstine	8	9.8	2.66	6	14
Patrick Bayou	15	4.8	2.73	1	10
Patrick Bayou (gunite)	6	2.8	1.47	1	5
Spring					
TCEQ	7	11.4	4.35	5	17
Dobberstine	13	8.8	2.65	5	14
Patrick Bayou	11	7.5	2.34	4	12
Patrick Bayou (gunite)	4	4.8	1.50	3	6

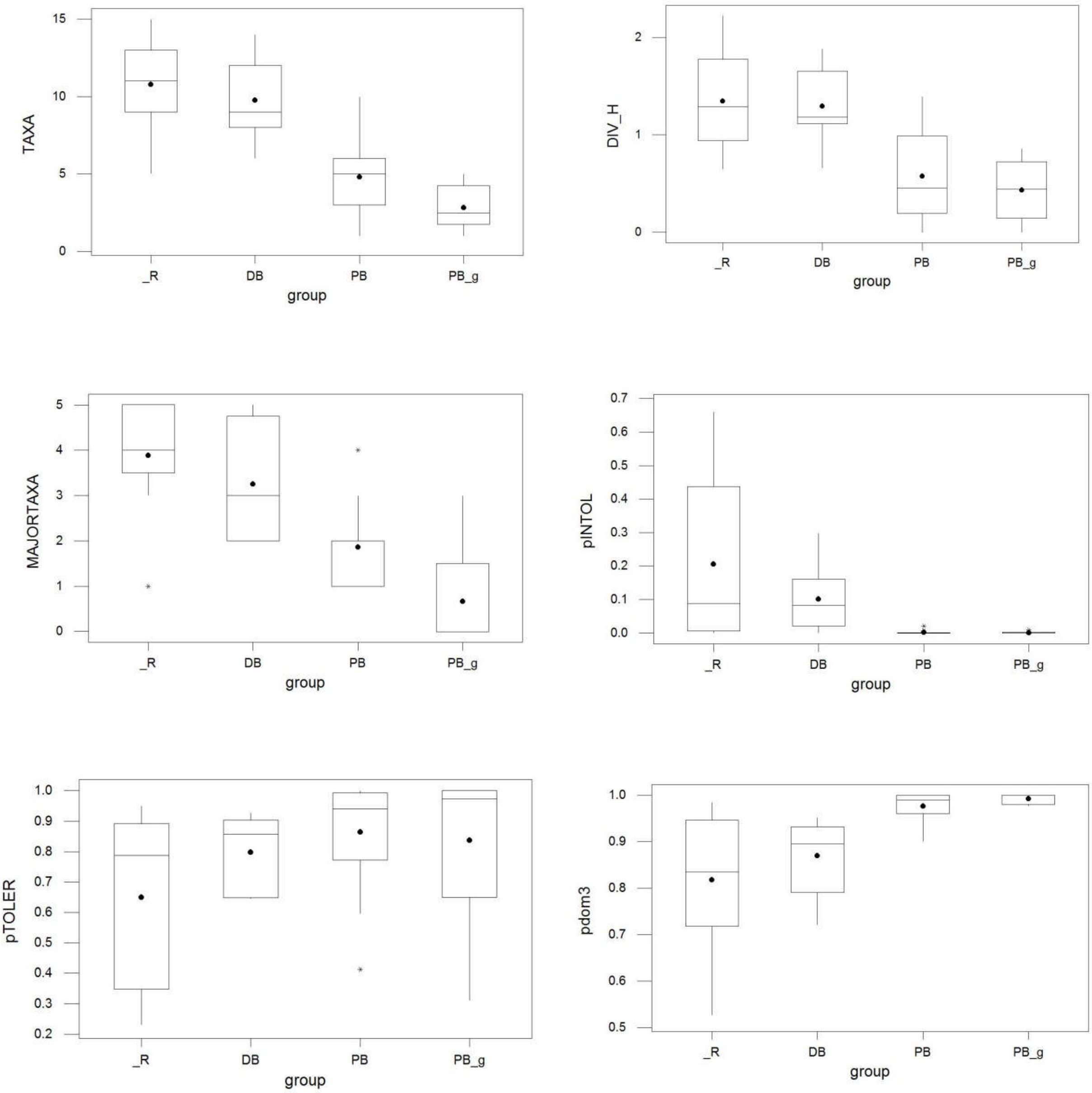

Figure 1. Box plots of the six metrics (Taxa, Diversity, Major Taxa, Percent Intolerant, Percent Tolerant, and Percent Dominant) among the four groups of samples (R = TCEQ reference samples, DB = Dobberstine reference samples, PB = main portion of Patrick Bayou with permanent substrate, and PB_g = gunite-lined portion of Patrick Bayou).

Diversity

Shannon-Weiner diversity (H') was significantly lower ($p<0.001$) in Patrick Bayou summer samples, with an average of 0.58 (PB) or 0.44 (PB-gunite) compared to average values of 1.35 and 1.30 for the two tributary groups (Table 6). Diversity values ranged from 0 to 1.39 in Patrick Bayou, and 0.65 to 2.22 in the other tributaries. As with taxa, the difference between diversity values in spring and summer in Patrick Bayou was greater than that for the comparison tributary groups. In spring, diversity values in Patrick Bayou averaged 1.19 compared to 0.58 in summer (Table 6). The comparison tributaries only showed slightly higher diversity in spring compared with summer (1.48 vs. 1.35), but they were consistently higher than the Patrick Bayou samples. The gunite lined portion of Patrick Bayou showed low diversity in both spring and summer (average 0.51 vs. 0.44).

Table 6. Diversity metric values by group and season.

DIVERSITY					
Summer	N	Mean	StDev	Minimum	Maximum
TCEQ	9	1.35	0.508	0.645	2.222
Dobberstine	8	1.30	0.387	0.66	1.881
Patrick Bayou	15	0.58	0.454	0	1.393
Patrick Bayou (gunite)	6	0.44	0.325	0	0.863
Spring					
TCEQ	7	1.48	0.490	0.606	2.108
Dobberstine	13	1.33	0.215	1.0762	1.6995
Patrick Bayou	11	1.19	0.356	0.376	1.641
Patrick Bayou (gunite)	4	0.51	0.435	0.103	0.905

Major Taxa

The presence or absence of polychaetes, crustaceans, bivalves, gastropods, and nemerteans in Patrick Bayou differed from the other tributary samples. In Patrick Bayou, the average number of these groups present was less than 2 in both seasons, while the average for the other tributary samples was greater than 3 (Table 7). None of these groups were present in four of the six samples collected from the gunite reach of Patrick Bayou, whereas all the other samples from Patrick Bayou (the lower reach in spring and summer and the gunite reach in spring) contained at least a polychaete (Table 8). In the comparison tributary data sets, all samples included a polychaete, and most exhibited at least one crustacean or a gastropod. The percentages of the samples in each group that contained the five taxa are shown in Table 8. Fewer Patrick Bayou samples included bivalves, gastropods, nemerteans, and crustaceans, compared to the reference tributary samples.

Table 7. Number of major taxa in each group by season.

MAJOR TAXA					
Summer	N	Mean	StDev	Minimum	Maximum
TCEQ	9	3.89	1.269	1	5
Dobberstine	8	3.25	1.282	2	5
Patrick Bayou	15	1.87	0.915	1	4
Patrick Bayou (gunite)	6	0.67	1.211	0	3
Spring					
TCEQ	7	3.1	1.215	1	4
Dobberstine	13	3.3	1.437	1	5
Patrick Bayou	11	2.0	0.775	1	3
Patrick Bayou (gunite)	4	1.8	0.500	1	2

Table 8. Percentage of samples in each group that contained at least one representative from each major taxon. (Seasons combined)

	TCEQ	Dobberstine	Patrick Bayou	Patrick Bayou - gunite
N=	*16*	*21*	*26*	*10*
Bivalvia	81%	33%	19%	0%
Crustacea	69%	62%	46%	10%
Gastropoda	63%	67%	12%	10%
Nemertea	44%	67%	15%	20%
Polychaeta	100%	100%	100%	60%

Percent Intolerant

Impaired benthic communities are often also characterized by the lack of more sensitive species or groups, in addition to the presence of tolerant organisms (Gibson et al. 2000). The percent of the community composed of intolerant organisms was much lower in Patrick Bayou than in the other tributaries. The average for this metric was about 0.2 % in Patrick Bayou, but over 20 % in the TCEQ tributary samples (Table 9). The Dobberstine samples averaged 10 %, which was lower than the TCEQ samples, but still much higher than the percent intolerant organisms in Patrick Bayou. Unlike other metrics, the percent intolerant individuals was not higher in the spring (compared to summer).

Table 9. Percent intolerant individuals metric values by group and by season.

PERCENT IN INTOLERANT TAXA					
Summer	N	Mean	StDev	Minimum	Maximum
TCEQ	9	0.2057	0.2608	0	0.6601
Dobberstine	8	0.1015	0.1003	0	0.2989
Patrick Bayou	15	0.0021	0.0054	0	0.0206
Patrick Bayou (gunite)	6	0.0016	0.0039	0	0.0094
Spring					
TCEQ	7	0.0620	0.1450	0	0.3902
Dobberstine	13	0.0370	0.0403	0	0.1299
Patrick Bayou	11	0.0010	0.0018	0	0.0045
Patrick Bayou (gunite)	4	0.0006	0.0011	0	0.0022

Percent Tolerant

When the proportion of the community that is composed of species known to be tolerant was compared, differences between Patrick Bayou and other tidal tributaries were evident. Patrick Bayou summer community data exhibited a higher proportion of tolerant organisms than the TCEQ reference or Dobberstine's samples (Table 10). The Patrick Bayou benthic community was composed of about 86% tolerant organisms. In contrast, benthic communities in the TCEQ comparison tributaries averaged 65% tolerant organisms. Dobberstine's samples exhibited about 80% tolerant organisms. In the spring, Patrick Bayou averaged 70% tolerant organisms compared to 54% in the TCEQ samples.

Table 10. Percent tolerant metric values by group and by season.

PERCENT IN TOLERANT TAXA					
Summer	N	Mean	StDev	Minimum	Maximum
TCEQ	9	0.650	0.286	0.231	0.951
Dobberstine	8	0.798	0.125	0.644	0.928
Patrick Bayou	15	0.865	0.185	0.413	1
Patrick Bayou (gunite)	6	0.837	0.274	0.310	1
Spring					
TCEQ	7	0.536	0.300	0.149	0.821
Dobberstine	13	0.604	0.239	0.208	0.929
Patrick Bayou	11	0.698	0.165	0.400	0.951
Patrick Bayou (gunite)	4	0.973	0.028	0.945	0.997

Percent Dominant

This metric measures the proportion of the community in the three most abundant taxa. Patrick Bayou samples were significantly higher than the other two groups ($p<0.001$), with Patrick Bayou averaging 98% compared to 82% and 87% for the other tributaries. Most of the groups were not different between spring and summer samples in terms of dominance (Table 11).

Table 11. Percent dominant metric values by group and season.

PERCENT IN DOMINANT 3 TAXA					
Summer	N	Mean	StDev	Minimum	Maximum
TCEQ	9	0.818	0.146	0.526	0.985
Dobberstine	8	0.870	0.085	0.721	0.952
Patrick Bayou	15	0.976	0.031	0.900	1
Patrick Bayou (gunite)	6	0.993	0.011	0.976	1
Spring					
TCEQ	7	0.826	0.119	0.610	0.966
Dobberstine	13	0.876	0.077	0.769	0.975
Patrick Bayou	11	0.903	0.074	0.757	0.994
Patrick Bayou (gunite)	4	0.992	0.012	0.974	1

Tidal Stream Benthic Index

When the six metrics above were combined, the resultant scores were significantly higher in both the TCEQ and the Dobberstine tidal tributary sample locations, averaging 35 and 29, compared to both Patrick Bayou groups, which averaged 13 and 8 on a scale of 0 to 60 (Table 12). In the two comparison tributary groups, spring scores were very similar to summer scores, on average. In Patrick Bayou, however, spring samples scored an average of 23 compared with the lower summer average of 13. A boxplot of the summer scores is provided in Figure 2.

Table 12. Results of combining the scores from the six metrics into one index score.

COMBINATION OF 6 METRICS					
Summer	N	Mean	StDev	Minimum	Maximum
TCEQ	9	35.43	15.63	10.43	53.06
Dobberstine	8	29.24	11.07	19.53	45.41
Patrick Bayou	15	13.01	7.64	2.77	31.50
Patrick Bayou (gunite)	6	8.08	7.84	0.77	18.78
Spring					
TCEQ	7	33.97	10.40	20.30	52.10
Dobberstine	13	29.99	7.38	19.93	42.04
Patrick Bayou	11	23.19	8.76	8.67	38.10
Patrick Bayou (gunite)	4	10.55	4.81	5.28	14.97

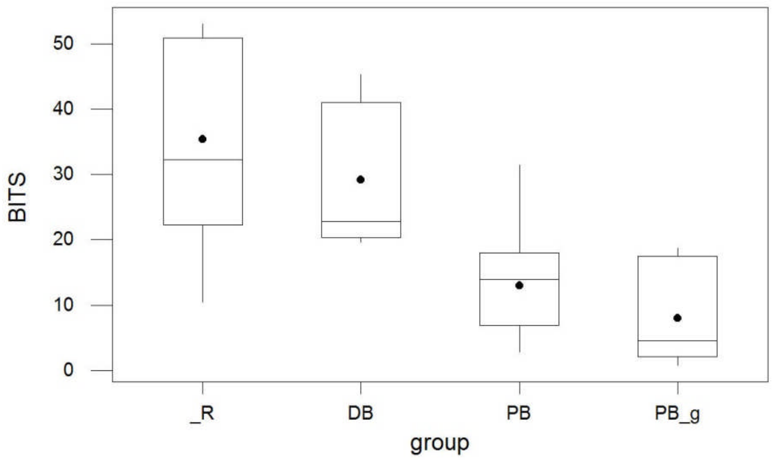

Figure 2. Box plot of the Benthic Index scores for the four groups of samples (summer only). The groups are: R = TCEQ reference samples, DB = Dobberstine reference samples, PB = main portion of Patrick Bayou, and PB_g = gunite portion of Patrick Bayou.

Effects of Sample Size

When the 9 TCEQ reference samples were split into 18 smaller samples, several of the metrics were not affected. The metrics based on percentages were quite similar on average, regardless of the sample size. However, number of taxa, diversity, major taxa, and the overall score were all affected by sample size to some extent (Table 13). The differences in the averages are shown in the following table. The largest effect was on the number of taxa per sample, where the standard sample size resulted in an average of 10.8 taxa per sample, but the smaller samples averaged 8.5 taxa per sample. This difference was statistically significant (p=0.04). Diversity was 0.07 units lower in the smaller samples, while the average number of major taxa decreased by 0.56 when the data were parsed into smaller samples. The overall score (Tidal Stream Benthic Index) was about 3 points lower in the small samples compared to the original samples. The differences in diversity, major taxa, and the benthic index score were not significantly different at p=0.05.

Table 13. Effect of sample size on metrics. Average metric values for the 9 original TCEQ reference samples (standard sample) and 18 subsets of those samples (small sample) that were based on half the original area.

	Standard Sample	Small Sample
	929 cm^2	464 cm^2
TAXA	10.8	8.5
DIVERSITY	1.35	1.28
%INTOLERANT	0.206	0.209
MAJOR TAXA	3.89	3.33
%TOLERANT	0.65	0.64
%DOMINANT	0.82	0.83
SUM OF 6 METRICS	35.4	32.5

Discussion

The benthic community of Patrick Bayou is impaired when compared to other benthic communities in Galveston Bay tributaries. This finding is consistent whether number of taxa, diversity, proportion of intolerant organisms, or a tidal stream benthic index is used. Patrick Bayou samples contained less than half the taxa found in other tributaries of Galveston Bay. Additionally, Patrick Bayou is dominated by tolerant organisms, and several important groups and species are absent or greatly reduced in Patrick Bayou (e.g. bivalves, gastropods, and nemerteans). It is evident from the box plots and the statistical analyses that there is very little similarity between the Patrick Bayou benthic community and that of the reference tributaries. A few of the sample locations in the reference group were probably impaired also, but the group as a whole still scored much better than Patrick Bayou.

These findings are consistent with the other available information on Patrick Bayou. The sediments of Patrick Bayou are contaminated with numerous compounds, including mercury, PCBs, PAHs, and dioxins (Anchor 2012). Historical sediment toxicity tests overall demonstrate acute and chronic toxicity. These are usually characteristics associated with degraded benthic communities (Brown et al. 2000, Engle and Summers 1999, Tetra Tech 2011) and, in fact, all the Patrick Bayou samples considered in the draft BERA would be considered degraded based on the presence of contaminants and sediment toxicity (using information in Parsons et al. 2002 compared with the criteria in Engle and Summers (1999) and TetraTech (2011)).

The Patrick Bayou benthic community appears to be more impaired in the summer than in the spring. In Galveston Bay and other bay systems, summer benthic communities are generally more stressed than at other times of the year. The reference tributaries did not show this pattern strongly. This can be attributed to the limited numbers of samples and variability in sample locations and sample years. Hence, spatial variability and interannual variability could affect the differences shown.

This evaluation also showed that the Dobberstine samples were not significantly different from the TCEQ samples in terms of any of the metrics tested, in spite of the different methods used in that study. The slightly lower scores that were observed for the Dobberstine samples compared to the larger TCEQ samples would be expected based on the sample size analysis performed on the TCEQ samples.

BERA Findings

The draft BERA report submitted to the EPA by the Anchor QEA on behalf of the Patrick Bayou industries in August 2012 included an analysis of the status of the benthic community. The draft BERA concluded that the Patrick Bayou benthic community was within the range of variability of the other tributary samples collected by Dobberstine. In the draft BERA, this conclusion was based on all Patrick Bayou samples from all seasons combined, which increases the apparent variability in Patrick Bayou. The draft BERA used multimetric indexes that were not developed for tidal streams and have not been shown to work on tidal stream benthic data. The indexes used in the draft BERA were designed to differentiate reference sites from degraded sites, as defined by sediment chemistry, sediment toxicity, and water column dissolved oxygen. Without question, all of the Patrick Bayou sample locations would be considered degraded using those criteria. If used as designed, the benthic community indexes should also classify the majority of the Patrick Bayou sample locations as degraded.

The conclusion that the Patrick Bayou benthic communities are within the range of benthic community data from reference tributaries is not supported. The basis for this assessment must be examined more critically. That is, benthic community data for Patrick Bayou based on samples collected in the spring should not be compared to summer samples collected elsewhere. Finally, metrics should be used that are appropriate and relevant to tidal stream habitats.

Summary

Benthic data collected from Patrick Bayou were compared to other benthic data from Galveston Bay tributaries collected by TCEQ (using the same sampling methods) and by Dobberstine (using slightly different sampling methods). Patrick Bayou benthos had significantly fewer taxa (4.8 compared to 10.8) and lower diversity (0.58 compared to 1.35) than the comparison locations. The benthic community of Patrick Bayou was primarily composed of tolerant species (87%), while the TCEQ (comparison) tributary stations averaged 65% tolerant organisms. Several important species and groups were missing from Patrick Bayou. The Patrick Bayou benthic community appeared to be more impaired in the summer than in the spring. Overall, the benthic community metrics for both spring and summer were lower than that for the uncontaminated sites in the other tributaries.

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Appendix 1. Summer 2000 Patrick Bayou samples. Species counts are number per sample (929 cm²). The letters "T" and "I" designate species considered tolerant or intolerant for this analysis.

		PB6A	PBT	PB5	PB4A	PBG	PB3	PBU	PBE	PBS	PB2.5	PBV
		September 2000										
Gastropoda							1					
Americamysis bahia												11
Ericthonius							1					
Gammarus							1					
Macrobrachium						2						
Chironomidae	T	10										
Nemertea	I				1					2		
Oligochaeta	T	715	36	5	2		1					
Amphicteis floridus		168	179		3					2		
Capitella capitata	T			10	9					3		
Mediomastus californiensis	I	6										
Laeonereis culveri	T		85	682	573	3	46	16	101	58	99	1
Neanthes succinea		40										
Parandalia americana											2	
Streblospio benedicti	T	4	5	11	6					32	14	170
ABUNDANCE		943	305	708	594	5	50	16	101	97	115	182
TAXA		6	4	4	6	2	5	1	1	5	3	3
DIV_H		0.7548	0.9884	0.1959	0.2012	0.673	0.3897	0	0	0.9409	0.4558	0.2619
pTOLER		0.7731	0.4131	1	0.9933	0.6	0.94	1	1	0.9588	0.9826	0.9396
pINTOL		0.0064	0	0	0.0017	0	0	0	0	0.0206	0	0
pdom3		0.9788	0.9836	0.9929	0.9899	1	0.96	1	1	0.9588	1	1
MAJORTAXA		1	1	1	2	2	3	1	1	2	1	2

Appendix 2. Patrick Bayou Summer 2003 samples. Abundance values are as reported in the draft BERA (Anchor 2012). The letters “T” and “I” designate species considered tolerant or intolerant for this analysis.

		PBE	PB3	PB4A	PB6A
		August 2003			
Mulinia lateralis	T	2.75			
Rangia cuneata	I	2.75			
Texadina		13.5	2.75		
Amphipoda		5.5			
Ampelisca					2.75
Idoteidae			8	2.75	
Ostracoda					
Chironomidae	T	10.75	8		5.5
Empididae (Diptera)					2.75
Nemertea	I				
Oligochaeta	T	427.75	1692	72.75	998
Hirudinea			5.5		
Amphicteis floridus		616	449.25	53.75	8
Capitella capitata	T		5.5	2.75	
Mediomastus californiensis	I		2.75		
Laeonereis culveri	T	390	1331.5	395.5	8
Polydora		5.5			
Streblospio benedicti	T	118.25	56.5	161.5	
ABUNDANCE		1592.75	3561.75	689	1025
TAXA		10	10	6	6
DIV_H		1.3934	1.1068	1.1392	0.1616
pTOLER		0.5961	0.8685	0.9180	0.9868
pINTOL		0.0017	0.0008	0	0
pdom3		0.9002	0.9750	0.9140	0.9893
MAJORTAXA		4	3	2	2

Appendix 3. Patrick Bayou Summer samples from gunite reach. Abundance values are as reported in the draft BERA (Anchor 2012). The letters “T” and “I” designate species considered tolerant or intolerant for this analysis.

		PB7	PBR	PBY	PBQ	PBR	PB7
		9/1/00	9/1/00	9/1/00	9/1/00	8/12/03	8/12/03
Ostracoda				1			
Chironomidae	T		1	1	3	13.5	13.5
Nemertea	I			1			
Oligochaeta	T	14	10	80	9	266.25	86
Hirudinea							5.5
Amphicteis floridus				23	29		
Streblospio benedicti	T				1		
ABUNDANCE		14	11	106	42	279.75	105
TAXA		1	2	5	4	2	3
DIV_H		0	0.3046	0.6759	0.8633	0.1934	0.5817
pTOLER		1	1	0.7642	0.3095	1	0.9476
pINTOL		0	0	0.0094	0	0	0
pdom3		1	1	0.9811	0.9762	1	1
MAJORTAXA		0	0	3	1	0	0

Appendix 4. Patrick Bayou Spring 2001 Samples. Abundance values are as reported in the draft BERA (Anchor 2012). The letters “T” and “I” designate species considered tolerant or intolerant for this analysis.

		PB6A	PBT	PB5	PB4A	PBG	PB3	PBU	PBE	PBS	PB2.5	PBV
Macoma mitchelli	T				1.1				5.4		1.1	1.1
Ericthonius								1.1	2.2	1.1		
Gammarus						1.1						
Idoteidae									2.2			
Ostracoda									2.2			
Cladocera							4.3					
Chironomidae	T	11.9	25.9	14	35.6	8.6	50.6		42	9.7		1.1
Odonata (Larvae)					1.1		1.1					
Turbellaria					1.1		1.1			2.2		
Nemertea	I						1.1			1.1		
Oligochaeta	T	339.4	29.1	2.2	4.3	2.2	36.6	34.5	36.6	30.2	3.2	5.4
Hirudinea							11.9					
Amphicteis floridus		18.3	18.3	14	9.7	55	93.7	33.4	90.5	38.8	86.2	200.4
Capitella capitata	T		1.1			1.1	1.1	1.1	6.5	8.6	55	145.5
Mediomastus californiensis	I											1.1
Laeonereis culveri	T	1.1	1.1	25.9	2.2	133.6	40.9	141.2	6.5	167	208	55
Neanthes succinea						1.1	1.1	1.1	6.5	8.6	55	145.5
Polydora											1.1	
Streblospio benedicti	T	1.1	2.2			1.1	1.1					23.7
ABUNDANCE		371.8	77.7	56.1	55.1	203.8	244.6	212.4	200.6	267.3	409.6	578.8
TAXA		5	6	4	7	8	12	6	10	9	7	9
DIV_H		0.3761	1.2960	1.1766	1.1501	0.9255	1.6408	0.9393	1.5760	1.2466	1.2810	1.4953
pTOLER		0.9508	0.7645	0.7504	0.7840	0.7193	0.5327	0.8324	0.4835	0.8062	0.6526	0.4005
pINTOL		0	0	0	0	0	0.0045	0	0	0.0041	0	0.0019
pdom3		0.9941	0.9434	0.9608	0.9002	0.9676	0.7572	0.9845	0.8430	0.8829	0.8525	0.8490
MAJORTAXA		1	1	1	2	2	3	2	3	3	2	2

Appendix 5. Patrick Bayou spring samples from the gunite reach. Abundance values are as reported in the draft BERA (Anchor 2012). The letters “T” and “I” designate species considered tolerant or intolerant for this analysis.

		PB7	PBR	PBY	PBQ
		4/1/01	4/1/01	4/1/01	4/1/01
Littoridina		5.4			
Idoteidae				2.2	
Chironomidae	T	78.7	176.7	19.4	14
Turbellaria		1.1			
Nemertea	I		1.1		
Oligochaeta	T	116.9	285.5	1186.3	377.1
Hirudinea		3.2	24.8		
Amphicteis floridus			1.1	1.1	1.1
Capitella capitata	T		1.1		
Streblospio benedicti	T	1.1			
ABUNDANCE		206.4	490.3	1209	392.2
TAXA		6	6	4	3
DIV_H		0.9053	0.8747	0.1028	0.1732
pTOLER		0.9530	0.9449	0.9973	0.9972
pINTOL		0	0.0022	0	0
pdom3		0.9738	0.9933	0.9991	1
MAJORTAXA		2	2	2	1

Appendix 6. Summer samples from July 2004 from Dobberstine (2007) as reported in the draft BERA. Bayous were Cedar Bayou, Robinson Bayou, and Double Bayou. The letters “T” and “I” designate species considered tolerant or intolerant for this analysis.

			CDR1	CDR2	CDR3	ROB1	ROB2	DBL1	DBL2	DBL3
			7/1/04	7/1/04	7/1/04	7/1/04	7/1/04	7/1/04	7/1/04	7/1/04
Macoma mitchelli	T	4	0	0	0	0	0	0	0	0
Mulinia	T	5	0	1	1	0	0	0	0	0
Littoridina		8	0	3	4	0	1	0	0	0
Rangia		17	2	0	9	0	4	0	0	0
Ostracoda		197	4	0	0	0	0	28	114	51
Edotea		18	3	1	2	0	0	0	0	2
Mysidopsis		10	9	0	0	0	0	0	0	0
Chironomidae	T	2043	9	5	11	477	255	508	695	63
Nemertea	I	41	9	5	5	1	0	0	1	2
Oligochaeta	T	3927	188	123	78	472	109	73	351	1225
Hirudinea		2	0	0	0	1	0	0	0	0
Capitella	T	37	0	10	15	0	0	0	0	0
Mediomastus	I	722	62	79	33	136	0	35	38	23
Laeonereis	T	177	3	1	3	23	10	63	10	45
Neanthes		7	0	0	1	4	0	0	0	0
Hypaniola		256	26	10	48	26	30	40	5	23
Parandalia		50	30	2	2	0	1	0	2	2
Polydora		6	0	0	0	0	0	0	0	0
Streblospio	T	485	62	41	96	0	13	0	36	0
IND/SAMPLE			407	281	308	1140	423	747	1252	1436
TAXA			12	12	14	8	8	6	9	9
DIV_H			1.695	1.524	1.881	1.18	1.11	1.121	1.186	0.66
pTOLER			0.644	0.644	0.662	0.853	0.915	0.862	0.872	0.928
pINTOL			0.174	0.299	0.123	0.12	0	0.047	0.031	0.017
pdom3			0.767	0.865	0.721	0.952	0.931	0.862	0.927	0.932
MAJORTAXA			4	5	5	2	2	2	3	3

Appendix 7. Spring samples from April 2004 from Cedar Bayou, Robinson Bayou, and Double Bayou from Dobberstine (2007) as reported in the draft BERA. The letters “T” and “I” designate species considered tolerant or intolerant for this analysis.

		CDR1	CDR2	CDR3	DBL1	DBL2	DBL3	ROB1	ROB2
Macoma mitchelli	T	1	0	0	0	0	0	0	0
Mulinia	T	0	0	0	0	4	1	0	1
Littoridina		0	1	0	0	0	0	1	0
Rangia		40	35	10	3	16	2	2	7
Corophium		1	0	0	0	0	0	0	0
Erichtainies		11	0	0	0	0	2	0	0
Ostracoda		1	0	0	0	0	0	0	0
Edotea		4	4	1	0	0	0	0	0
Mysidopsis		0	0	0	0	0	0	1	1
Chironomidae	T	2	16	21	83	188	125	39	121
Nemertea	I	2	1	1	0	0	1	10	4
Oligochaeta	T	133	221	62	54	127	119	155	341
Hirudinea		0	0	0	0	0	0	0	1
Capitella	T	0	2	16	0	0	0	0	0
Mediomastus	I	13	6	4	0	0	0	16	13
Laeonereis	T	1	0	0	8	4	1	4	94
Hypaniola		232	181	81	55	19	26	38	17
Parandalia		8	0	0	0	2	0	1	0
Polydora		0	2	0	0	0	0	0	0
Streblospio	T	42	48	16	0	0	0	128	2
IND/SAMPLE		491	517	212	203	360	277	395	602
TAXA		14	11	9	5	7	8	11	11
DIV_H		1.505	1.398	1.616	1.261	1.129	1.076	1.528	1.254
pTOLER		0.365	0.555	0.542	0.714	0.897	0.888	0.825	0.929
pINTOL		0.031	0.014	0.024	0	0	0.004	0.066	0.028
pdom3		0.829	0.87	0.774	0.946	0.928	0.975	0.815	0.924
MAJORTAXA		5	4	4	2	3	5	4	5

Appendix 8. Summer samples from TCEQ stations.

		SS3	SS24	SS25	SS26	SS28	SS36	ABMC	ABMS	ABLS
		7/24/97	7/8/97	7/8/97	7/15/97	7/15/97	6/30/97	7/29/02	7/29/02	7/29/02
Bivalvia		1		1						
Macoma mitchelli							3			
Mulinia lateralis	T		1			1	1			1
Rangia cuneata	I	18						1		
Gastropoda								1		
Boonea impressa				1						
Probythinella louisianae		4					6			
Pyramidellidae				1						
Texadina										19
Texadina barretti				1						
Texadina sphinctostoma		5	2	1	1					
Crustacea										
Americamysis				3						
Americamysis bahia		3	8	9	1		12			5
Amphipoda						1	2			
Corophium										3
Edotea										4
Lepidophthalmus jamaicense						1				
Insecta			1							
Ceratopogonidae								4	4	3
Chaoborus								1		
Chironomid (2pr eyes)	T	28						3	3	15
Chironomidae	T	2	11		2	3	9	48	64	10
Nemertea	I	2		8	6	6				8
Oligochaeta	T	9	1	5	4		4	144	381	2
Hirudinea						1				
Polychaeta								1		
Amphicteis floridus			1		1		33	16	19	19
Capitella capitata	T			7	8	5				
Cossura delta					2					
Hesionidae							2			1
Laeonereis culveri				6		3				1
Mediomastus	I		1	126	2	42	9			20
Parandalia		1		1	1	9				
Podarkeopsis brevipalpa				3						
Streblospio benedicti	T	4	95	30	62	6	221			41

Appendix 8 (cont.).

	SS3	SS24	SS25	SS26	SS28	SS36	ABMC	ABMS	ABLS
ABUNDANCE	77	121	203	90	78	302	219	471	152
TAXA	11	9	15	11	11	11	9	5	15
DIV_H	1.8723	0.8535	1.4372	1.2914	1.6745	1.0929	1.0298	0.6450	2.2218
pTOLER	0.5584	0.8926	0.2365	0.8444	0.2308	0.7881	0.8904	0.9512	0.4605
pINTOL	0.2597	0.0083	0.6601	0.0889	0.6154	0.0298	0.0046	0.0000	0.1842
pdom3	0.7143	0.9421	0.8128	0.8352	0.7215	0.8779	0.9498	0.9851	0.5263
MAJORTAXA	5	4	5	4	4	4	3	1	5

Appendix 9. TCEQ Spring samples from Armand Bayou and Halls Bayou. Abundance values are number per sample (929 cm²).

		ABUS	ABMC	ABLS	HBUS	HBMC	HBMS	HBUC
		4/22/02	4/24/02	4/24/02	4/29/02	4/29/02	4/29/02	5/2/02
Bivalvia		6		1		1		1
Mulinia lateralis	T					1		
Rangia cuneata	I	1			1		5	
Texadina				2	1	1		
Amphipoda				3	1			
Corophium				1			3	
Edotea montosa				1			10	
Ostracoda		6		1				
Rhithropanopeus harrisii							1	
Taphromysis		1					2	
Insecta		1					5	
Coleoptera							5	
Plecoptera		1						
Trichoptera		4				3		
Diptera		1		5	4		5	2
Ceratopogonidae		67			4	1	16	
Chironomid 2pr eyes	T	49	2	62	145		106	5
Chironomid spE	T	150	44	35	11	4	10	8
Chironomidae	T	2		5	3	2	5	1
Nemertea	I					5	1	
Oligochaeta	T	144	25	2	158		105	12
Amphicteis floridus			497	380	58	9	72	3
Mediomastus	I			13		11		
Namalycastis abiuma							2	
Nereidae		2						
Parandalia						1		
Polydora				3				
Streblospio benedicti	T		16	78		2	6	
ABUNDANCE		435	584	592	386	41	359	32
TAXA		14	5	15	10	12	17	7
DIV_H		1.5605	0.6058	1.2651	1.2984	2.1084	1.9006	1.6162
pTOLER		0.7931	0.1490	0.3074	0.8212	0.2195	0.6462	0.8125
pINTOL		0.0023	0	0.0220	0.0026	0.3902	0.0167	0
pdom3		0.8280	0.9659	0.8769	0.9352	0.6098	0.7839	0.7813
MAJORTAXA		3	1	4	4	4	4	2